

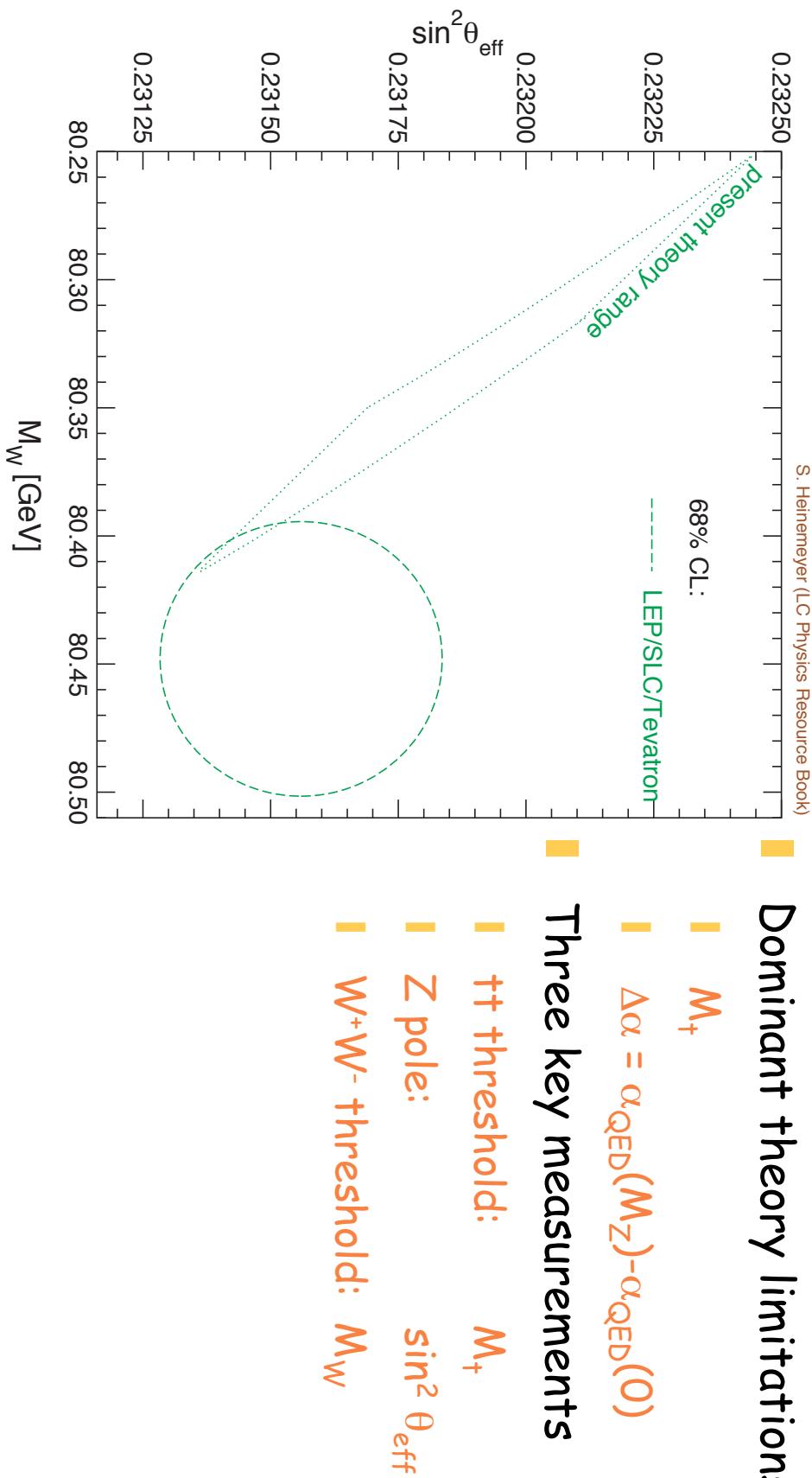
Revisiting EW Constraints at a Linear Collider

Work done by

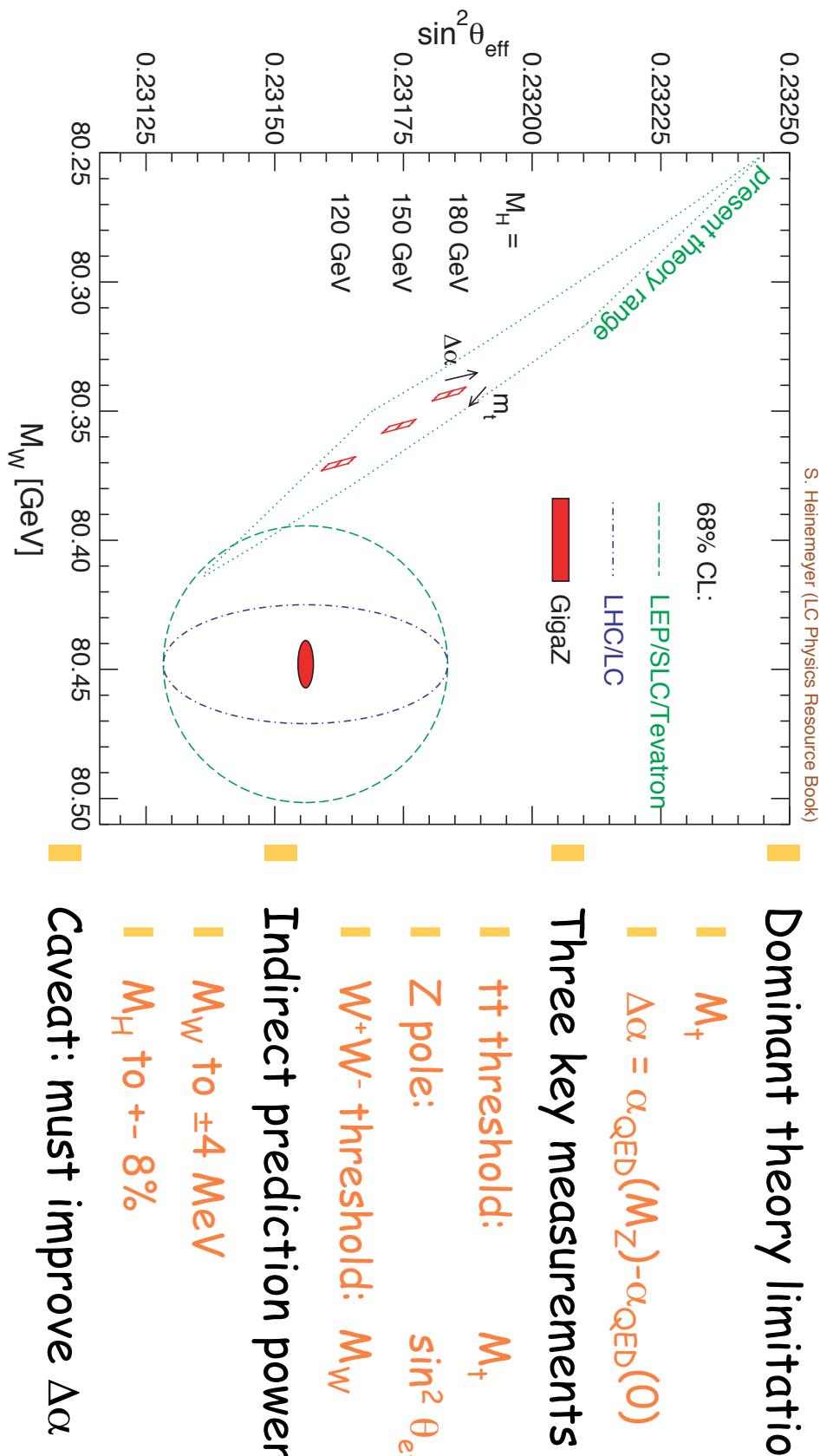
S. Heinemeyer	P. Rowson	U. Baer
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Why improve EW parameters?



Why improve EW parameters?



$t\bar{t}$ threshold: M_t



- Kinematic reconstruction

- Hadronic machines systematics limited

- M_t to $\sim \pm 2\text{-}3\text{ GeV}$

- Measures \sim pole mass

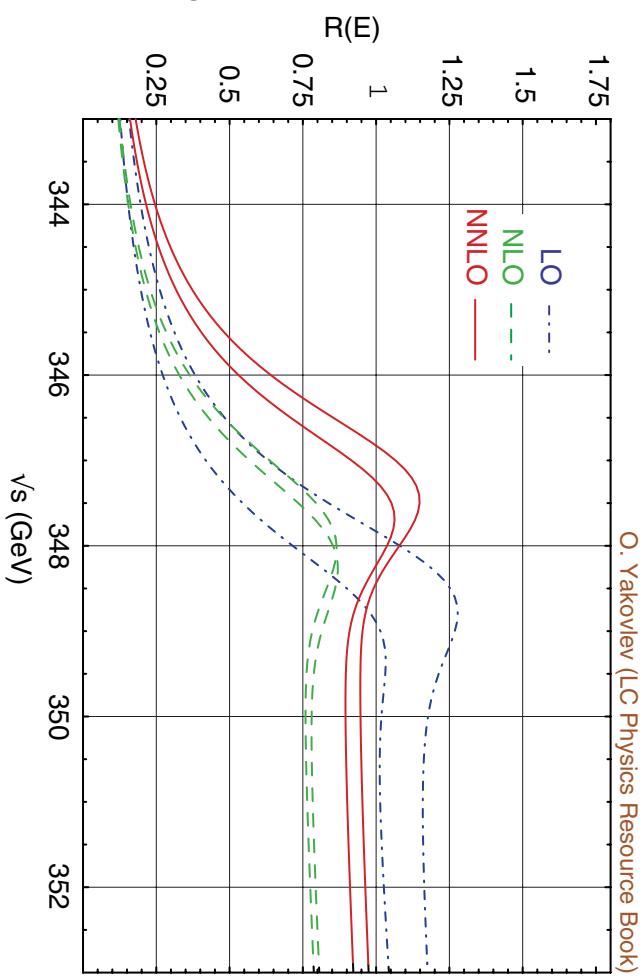
- Pole mass ill-defined in QCD

- Nonperturbative ambiguity of $\theta(\Lambda_{QCD})$ in definition

- Eg., poorly-behaved perturbation series for threshold cross-section

- Want short-distance mass, eg. $\bar{M}_t(M_t)$

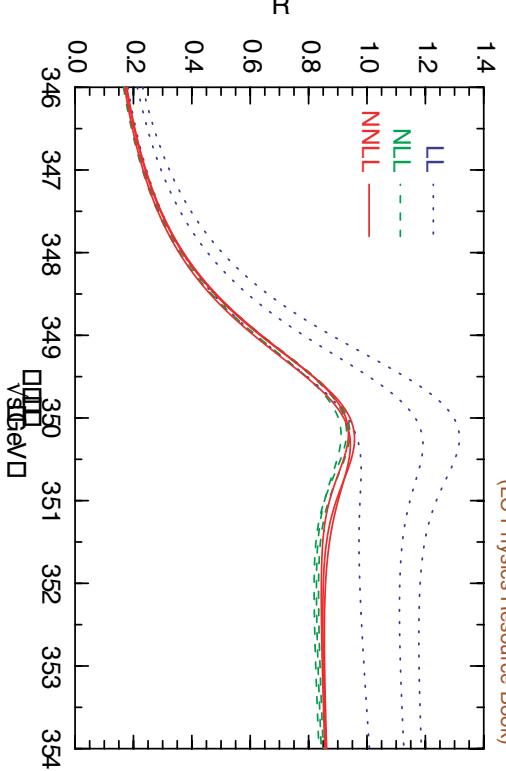
- EW constraints, ΔM_B , ...



$t\bar{t}$ threshold: M_t



- Large Γ_t (~ 1.4 GeV) a boon
- $\Gamma_t \gg \Lambda_{QCD} \Rightarrow$ no narrow resonances, smooth line shape
- Allows calc. in pert. QCD
 - infrared cutoff, smearing
- A few short-distance mass def's near threshold
 - 1S peak position stable to ~ 200 -300 MeV
 - Masses related to \overline{MS} mass via pert. QCD series
- Modest luminosity required
 - $10 \text{ fb}^{-1} \rightarrow \pm 40 \text{ MeV stat. uncertainty}$



M_t to ± 200 MeV

Other top measurements

- Threshold
- Total top width
 - Peak $\sigma \sim 1/\Gamma_t$
 - $100 \text{ fb}^{-1} \rightarrow \sim 2\% \text{ uncertainty}$
- Yukawa coupling
 - $115 \text{ GeV Higgs} \rightarrow 5\text{-}8\%$ increase in threshold σ
 - 2-3% uncertainty in predicted cross section
 - 14-20% on Yukawa coupling
 - Sensitivity drops for increasing Higgs mass
- High energy
 - Yukawa coupling
 - $e^+e^- \rightarrow t\bar{t}h \rightarrow W^+W^-bb\bar{b}\bar{b}$
 - $800 \text{ GeV} (1000 \text{ fb}^{-1})$: $\sim 5.5\%$
 - 500 GeV : $\sim 4\times$ worse
 - All neutral and charged current couplings
 - Measure/limit most form factors at 1% level
 - $500 \text{ GeV}, 100\text{-}200 \text{ fb}^{-1}$
 - $t\bar{t}Z$ couplings unique to LC
 - production polarization asymm.
 - Test QCD, EW radiative corr.
 - $\sigma(e^+e^- \rightarrow t\bar{t} \rightarrow l\nu jjjj)$ to $< 1\%$

$\sin^2\theta_W$ status



LEPEWWG, summer 2001

Preliminary

$A_{fb}^{0,l}$
 0.23099 ± 0.00053

$A_l(P_\tau)$
 0.23159 ± 0.00041

$A_l(\text{SLD})$
 0.23098 ± 0.00026

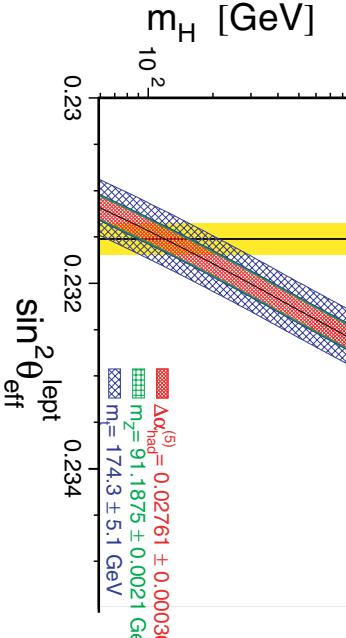
$A_{fb}^{0,b}$
 0.23226 ± 0.00031

$A_{fb}^{0,c}$
 0.23272 ± 0.00079

$\langle Q_{fb} \rangle$
 0.2324 ± 0.0012

Average

0.23152 ± 0.00017
 $\chi^2_{\text{d.o.f.}}: 12.8/5$



- $A + Z$ pole: dominated by
- LEP b quark A_{FB}^b
- SLD A_{LR}
- A_{FB}^b : not in best agreement w/ SM
- Lower energy scales
- Recent NUTeV result
- "3 σ high"
- atomic parity violation
- $\sim 2\sigma$ low

Giga-Z

- Revisit Z pole with a linear collider
 - Expect $\mathcal{L} \sim 5 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$
 - $10^9 Z$ decays in $\sim 10^7 \text{ s}$
 - Could contemplate interruption of high energy program
 - $10^{10} Z$ decays: 3-5 year program
 - Would need simultaneous low energy/high energy running
 - Mainly heavy flavor program benefits
- Polarization
 - 80% electron polarization a given
 - positron polarization an enormous boon: achievable?
 - 60% polarization desirable

Z pole scan

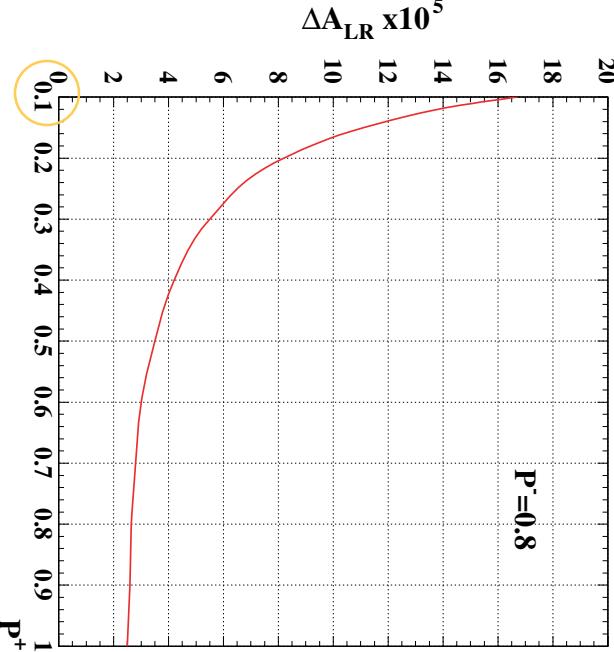
- **Measured**
 - M_Z
 - Γ_Z
 - $\sigma_0 \propto \Gamma_{\text{had}} \Gamma_{||} / \Gamma_Z^2$
 - $R_l = \Gamma_{\text{had}} / \Gamma_{||}$
- **Extracted**
 - $M_Z: \pm 2 \text{ MeV} \rightarrow \text{LC E scale}$
 - $\alpha_s(M_Z^2): \pm 0.0027 \rightarrow \pm 0.0009$
 - $\rho_l: \pm 0.001 \rightarrow \pm 0.0005$
 - $N_V: \pm 0.008 \rightarrow \pm 0.0004$
- **Current measurements systematics limited**
 - **2x improvement on eff. syst. (no th'y improvement for \mathcal{L})**
 - $4 \times R_l$, 30% σ_0 improvements
 - $\delta E_{\text{beam}} / E_{\text{beam}}$: potentially 10^{-5} w/ Moller spectrometer?
 - 2x Γ_Z improvement
 - **Energy spread: beamstrahlung to $\mathcal{O}(2\%)$: further study needed**
 - Γ_Z, ρ_l limited otherwise
 - monitor with Bhabha acolinearity? 5 point scan?

$A_{LR} \rightarrow \sin^2 \theta_W$

- A_{LR} the most sensitive variable to $\sin^2 \theta_W$

$$A_{LR} = \frac{1}{P_- N_L + N_R} = A_e = 2 \frac{1 - 4 \sin^2 \theta_W^{eff}}{1 + (1 - 4 \sin^2 \theta_W^{eff})^2}$$

- *GigaZ = 2000x SLD*
- SLD: $A_{LR} = 0.1514 \pm 0.0022$



- e^+ polarization:
 - None: $\delta P_+/P_-$ dominates uncertainty: 0.25% (optimistically) feasible
 - ΔA_{LR} to 4×10^{-4}
 - With: use Blondel scheme (combine $N_{LL}, N_{RR}, N_{LR}, N_{RL}$)
 - 60% P_+ \leftrightarrow effective 95% polarization, don't need absolute polarization
 - $\Rightarrow \Delta A_{LR}$ to 10^{-4}

$A_{LR} \rightarrow \sin^2 \theta_W$: experimental issues

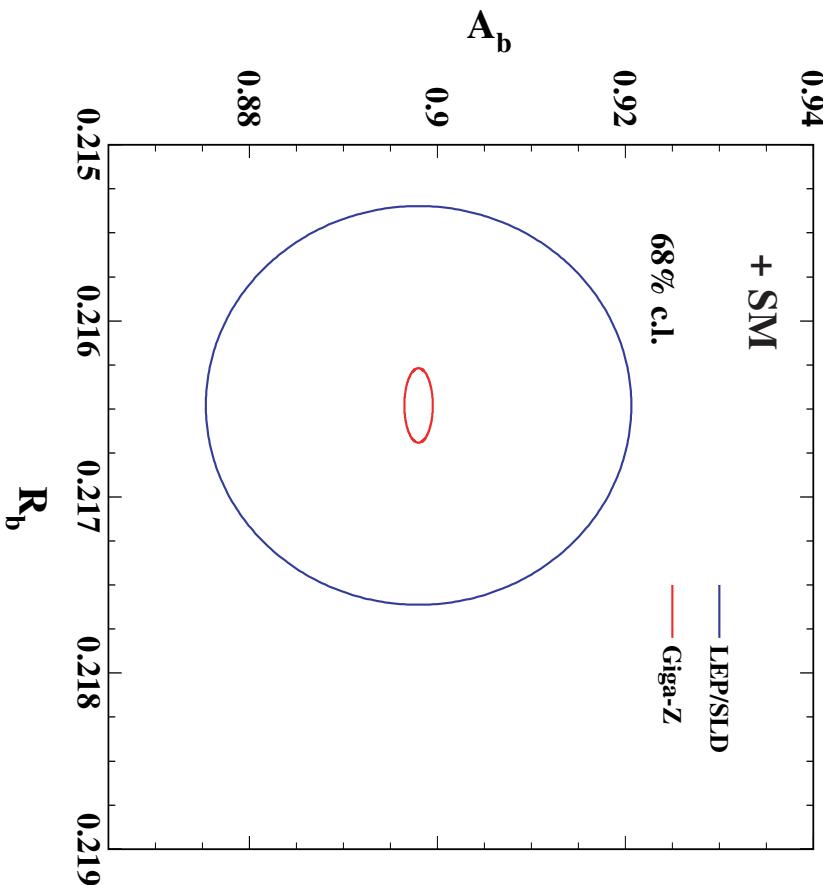
- polarization
 - Blondel scheme: need relative L,R polarizations to 10^{-4}
 - | Appears feasible
 - Systematics: polarimeters after IP?
 - Difficult w/o crossing angle
 - Can positron helicity be switched rapidly enough relative to beam stability?
 - What is the relevant time scale?

$A_{LR} \rightarrow \sin^2\theta_W$: experimental issues

- Z- γ interference: A_{LR} changes rapidly away from pole
- Control $\delta E/E$ to 10^{-5}
- Control of beamstrahlung (effective vs shift)
 - Ignore: A_{LR} shift of 9×10^{-4} at TESLA, much worse at NLC
 - E scale from Z pole scan + LEP M_Z . Same beam parameters?
 - Trade \mathcal{L} for reduced beamstrahlung
 - NLC: $125 \rightarrow 18$ MeV E shift for factor 5 \mathcal{L} penalty
- If beam issues controlled:

$$\sin^2\theta_W \text{ to } \pm 0.000013$$

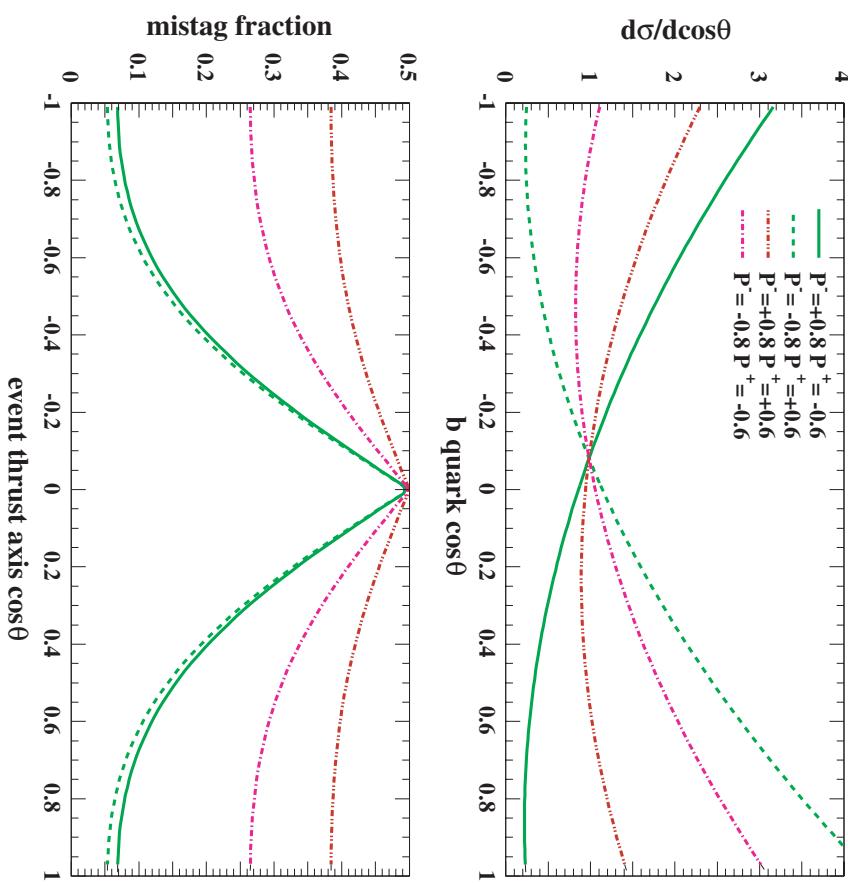
Zbb vertex



- $A_b: 2.5\text{-}3.5 \sigma$ discrepancy w/ SM persists
- **Stat's dominated measurement**
- **Complementary sensitivity to "new physics" than S, T, U**
- $R_b = \Gamma_{bb} / \Gamma_{had}$
- **Measure corrections to Zbb vtx**
 - EW prop., QCD corr. cancel
- **5x improvement from b-tagging**
- $A_b (= 3/4 A_{FB,LR})$
- $P^+ = 60\%: 15\times$ improvement
- $P^+ = 0: 6\times$ improvement

b physics at Giga-Z?

- Great potential
- Production flavor tagging
 - $\varepsilon D^2 \sim 0.6$ vs 0.1-0.25
 - $D = 1 - 2P(\text{mistag})$
- Large boost
 - b's well-separated
 - Excellent b tagging
- Well-defined initial state:
 - "v-reconstruction"
- Stiff competition
- Mainly cross checks others on "standards"
 - CKM unitarity angles
 - Δm_s



Some unique b physics

- $B_s \rightarrow X l \bar{\nu}$ rate
- Constrain uncontrolled uncertainty in OPE from quark-hadron duality violations
- Polarized Λ_b decays (G. Hiller)
- Probe $b_R \rightarrow q_L \gamma$ (SM) vs $b_L \rightarrow q_R \gamma$ (new physics)
 - $10^9 Z$'s gives interesting reach in $\theta(\text{spin}, p_\gamma)$ asymmetry
- $B \rightarrow X_s \nu \bar{\nu}$
- Emiss constraints + well-separated b decays allow access
- Non-SM physics affects $X_s \nu \bar{\nu}$, $X_s l^+ l^-$ differently
 - reach? $B \rightarrow \tau \nu$ bkg?
- Production flavor tagged $B \rightarrow \pi^0 \pi^0$

W^+W^- threshold: M_W

- Potential indirect precision: $\delta M_W \sim \pm 4$ MeV
 - Tevatron/LHC: expect 15-20 MeV precision (syst. limited)
- EW constraints: can LC approach indirect precision?
 - E_{beam} , beamstrahlung appear to be most serious issues
 - high energies: direct reconstruction needs E_{beam} constraint
 - E scale likely to be pinned via M_Z
 - Beamstrahlung scales as $(E_{beam})^2$
 - Threshold needs:
 - $E_{beam} \rightarrow 10^{-5}$: potentially $e^+e^- \rightarrow \gamma Z, Z \rightarrow \mu\mu, ee?$
 - Stat's for \sqrt{s} vs time?
 - Beamstrahlung: control shape distortion to 0.12% $\leftrightarrow \pm 2$ MeV
 - Bhabha acolinearity?
 - Theory: cross section shape to 0.12%

W^+W^- threshold: M_W

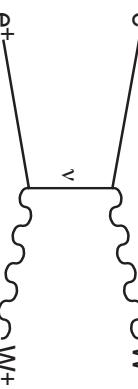


- 100 $\text{fb}^{-1} \rightarrow \pm 5 \text{ MeV}$ (stat)

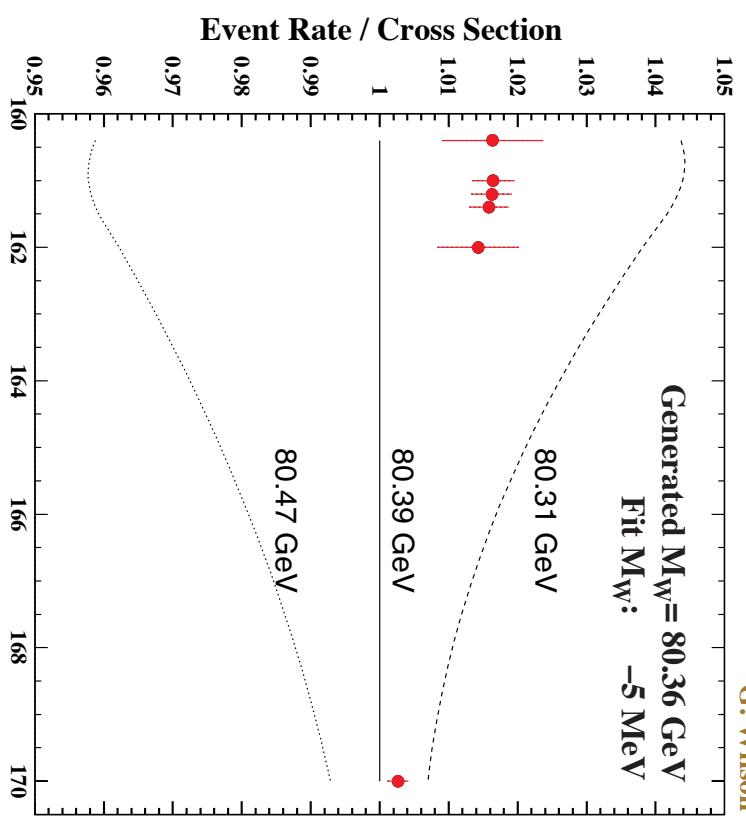
- 60% e^+ polarization

- $\sim 10^7$ sec

- Strategy: t-channel dominates



- 75% $e_R^+ e_L^-$
- 15% $e_L^+ e_R^-$ (\sim no W^+W^-)
- 10% other



- Polarization

- 0.25% absolute or $e^+e^- \rightarrow \gamma Z$ + Blondel scheme

- $P_z = 0$: doubles \mathcal{L} required

M_W to $\pm 7 \text{ MeV}$

EW reach summary

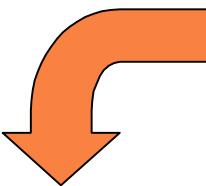
(U. Baer *et al*, hep-ph/0111314)

	now	Tev. Run II A	Run II B	Run II B*	LHC	LC	GigaZ
$\delta \sin^2 \theta_{\text{eff}} (\times 10^5)$	17	78	29	20	14-20	(6)	1.3
δM_W [MeV]	33	27	16	12	15	10	7
δm_t [GeV]	5.1	2.7	1.4	1.3	1.0	0.2	0.13
δM_H [MeV]	—	—	$\mathcal{O}(2000)$	100	50	50	

Run II B: 15 fb⁻¹
Run II B*: 30 fb⁻¹

LC improvement in $\sin^2 \theta_{\text{eff}}$:

dedicated fixed target Moller scattering exp.



GigaZ improvement in M_t :

from improved α_s (Z pole scan)

$\delta M_H / M_H$ from:	M_W	$\sin^2 \theta_{\text{eff}}$	all
now	106 %	60 %	58 %
Tevatron Run II A	72 %	39 %	35 %
Tevatron Run II B	37 %	33 %	25 %
Tevatron Run II B*	30 %	29 %	23 %
LHC	22 %	25 %	18 %
LC	15 %	24 %	14 %
GigaZ	12 %	8 %	8 %

Constraint potential: S, T, U



S, T, U

| Parameterize effect of new
physics on W, Z vacuum pol.

| EW variables linear fcn's of STU

| Sensitivity (now $\rightarrow LC/GigaZ$)

| $S: \pm 0.11 \rightarrow \pm 0.05$ (± 0.02 w/ $U=0$)

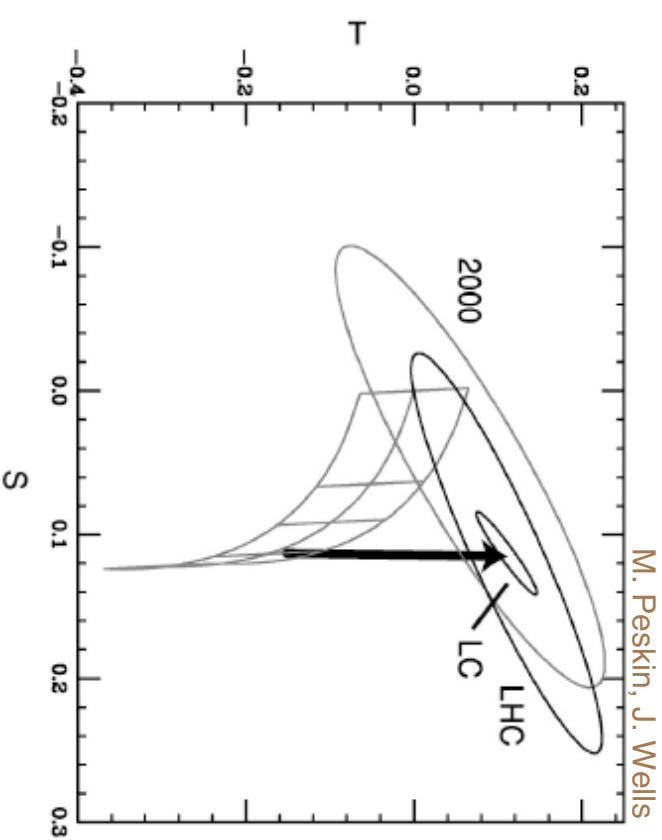
| $T: \pm 0.14 \rightarrow \pm 0.06$ (± 0.02 w/ $U=0$)

| $U: \pm 0.15 \rightarrow \pm 0.04$

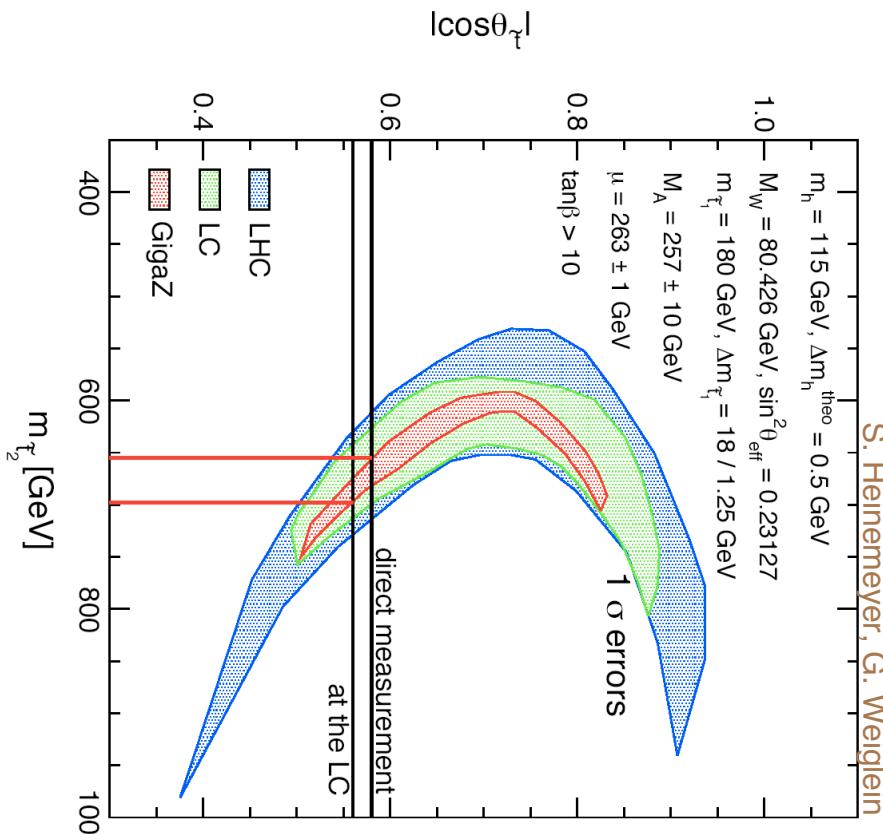
| Peskin, Wells (PRD 64, 093003)
eg. technicolor

| Survey models w/ heavy Higgs:

- | Significant dev's in S, T from SM
observable w/ GigaZ



Constraint potential: SUSY



- **MSSM Higgs, light scalar top seen at Tevatron/LHC/LC**
- **$e^+e^- \rightarrow \tilde{t}_1 \tilde{t}_1^*$ at LC yields**
- **\tilde{t}_1 mass, stop-sector mixing to 1%**
- **Various MSSM constraints**
- **$\sin^2 \theta_W$ vs M_W predicted vs. measured**
- **M_h predicted vs measured**
- **Constraint on mass of heavy scalar top**

Conclusion

- Low energy program adds great value to the overall LC and general HEP program
- **Powerful constraints provide**
 - Self-consistency checks for interpretation of new particles
 - Extension of effective mass reach
- **Unique flavor physics contributions a bonus**
- Beam energy and polarization issues need further study
- **Solutions will involve monitoring instrumentation that must be allowed for in baseline designs**